STATUS OF THE J-PARC RFQ

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Abstract

The J-PARC linac has been delivered 181 MeV beams since January 2007. Trip rates for the RFQ, however, unexpectedly increased from the autumn of 2008, and this has been hindering operations for user runs. We tried to recover by improvement of vacuum properties, modification of RF interlocking and so on. As a result of these measures and further RF conditioning, the condition of the RFQ has been almost restored to its previous condition.

INTRODUCTON

The J-PARC RFQ (length 3.1m, 4-vane type, 324 MHz) accelerates a beam from the ion source to the DTL (Drift Tube Linac). The linac beam test started in November 2006 and a 181 MeV beam was successfully accelerated in January 2007. Since then, the linac has been delivered beams for commissioning of the linac itself, downstream accelerators and research facilities. Trip rates for the RFQ, however, unexpectedly increased in September 2008, and this has been disrupting operations for user runs. We tried to restore the performance of the RFQ, but our efforts were fruitless. So we decided to construct a backup spare RFQ[1,2]. Table 1 shows the evolving RFQ and the linac condition.

COUNTERMEASURES

We assumed that the trouble came from damages done during operation and conditioning, because previously we had been operating the RFQ for hundreds of hours without trouble. After the initial trouble, we undertook several measures such as changing the RF interlock setting and better suppression of un-expecting beam injection.

During the RF rise time, the interlocks were masked to allow the RF filling to the RFQ to be as fast as possible. But that means ignoring the possibilities that an excess klystron power could be fed into the RFQ. Therefore, we changed the mask to make the interlock enabled almost all the time.

Once a trip occurred, the RF system tried to restart the RFQ pulse by as many as several ten of times. Obviously, this might cause damage to the RFQ. Thus the maximum re-try limit was reduced to 5. If an automatic restart fails, an operator can restart the RF while monitoring the vacuum pressure and waveforms.

The ion source starts arching about 0.5 msec prior to beam acceleration. As a result, when extraction voltage would be applied as its normal timing, beam would be injected into the RFQ. But as the RF had been turned off; all the beam would be lost in the RFQ. Recognizing this, the timing of the extraction voltage application as delayed as much as possible before the acceleration to reduce un-expecting beam injection.

OPERATION AFTER MEASURES

We had an RF high power conditioning session in November 2008 after the above measures had been taken and then beam operation was restarted in December. The results disappointed us; the trouble returned after only a few days of 24 hour beam operation. We did another conditioning for several days and the voltage that could be sustained without tripping was recovered. In this way, we managed to clear the important project milestones, so that able to initiate Main Ring acceleration studies and user operation of the Material and Life experimental facilities (MLF) by the end of 2008.

There were some operational voltage bands where much outgassing was observed and that gas seemed to prevent further voltage rise. The major bands were at around 65% and 85% of the 100% design voltage, which corresponds to a maximum field about 32 MV/m. Hypothesizing the cause to be that multipacting was occurring at some places in the RFQ, we tried to arrange that the RF rise time through these regions should be as fast as our RF system allowed.

As we surveyed the breakdown and recovery cycles, we seldom saw any troubles when there was beam operation during the daytime and conditioning at night; but we saw trouble when in 24 hour operation. We suspect that some contaminants were accumulated during long operating

Table 1: Evolution of the RFQ and the linac condition.

	Event	RF/beam widths (us)	I-Peak (mA)	Pwr@ MLF (kW)	Condition or Cont. op. days
Sept. 2008	Trip rate increase	200/100	5		very poor
Nov.	Improvement: interlock,conditioning, etc.				
Dec.	MR study and MLF user program after conditioning	155/100	5	20	poor
Jan. – Feb. 2009	Conditioning and operation user program was cancelled	155/100	5	20	poor
Mar.	Vacuum system improvement: ion pumps, diagnostics				
June	MLF user program	155/100	5	20	2
Jul.-Sept.	Vacuum improvement: Cryo. Pumps. baking, oil-free pumps				
Nov. - Jan.	MLF user program	255/200	15	120	2 to 3
Dec.	MLF high power demonstration (1hour)	555/500	15	300	
Jan. 2010	Demonstration of continuous operation for 6 days	255-555 /200-500	15	120	6
Feb. - Mar.	MR and HD/NU study, beam delivery	555/200 -500	15	can-celled	7 to 6
Arp.- May	MLF, MR(NU) beam delivery	555/200 -500	15	120	13(max.)

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runs, but that somehow the RFQ has a cleaning process during intermittent operation.

Since January 2009, the first priority has been to operate on schedule rather than to increase beam power. So from December we stayed with a conservative regime: peak current of 5 mA, beam pulse width of 0.1 ms, and a repetition of 25 Hz. That corresponds to an MLF beam power of 20 kW, which is the minimum acceptable for users. Even under those conditions, the RFQ disrupted use for a few months.

VACUUM SYSTEM IMPROVEMENT

We understood that good vacuum properties were essential for RFQ performance. The RFQ took several days to pump down because it had a complicated dual structure; an RF structure inside a vacuum vessel. And we had to consider the risk of worsening the condition when the vacuum was purged. Finally, by March 2009 we decided to change the vacuum system to improve the pumping speed because it seemed there was no other way forward. We added two ion pumps to the RFQ, one turbo molecular pump in the LEBT (Low Energy Beam Transport), and an orifice in the LEBT to reduce gas flow, and a moisture filter in the hydrogen gas system of the ion source. For diagnostics we put in a cold cathode gauge and a quadrupole mass analyzer. The RFQ vacuum system including the summer improvements is shown in Fig. 1.

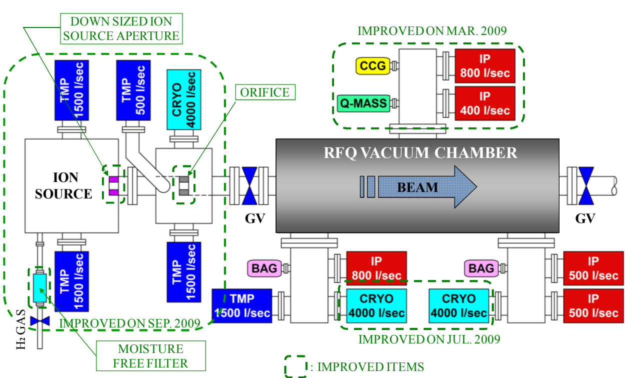

Figure 1: Vacuum system.

After the purge and vacuum system improvements and 10 days of evacuation, we began conditioning and test operations from March to May. In June, we successfully delivered beam to the MLF users without any unscheduled breakdown suspension.

The results of the Q mass analyzer measurements show that some hydrocarbon components such as C(mass of 12), CO(28), CO2(44) etc., are entering from the LEBT when the gate valve is opened (see Fig. 2). These components are thought to be coming from back streaming oil from the oil rotary roughing pumps in the LEBT and ion source.

We then undertook an essential 2nd vacuum system improvement during the summer shutdown. The oil rotary pumps were replaced with oil-free scroll pumps. Also, we replaced the old LEBT chamber with a new clean chamber having a divider plate with an orifice for differential pumping. One cryo pump was installed on the RFQ side and one 1500L/s turbo molecular pump on the ion source side.

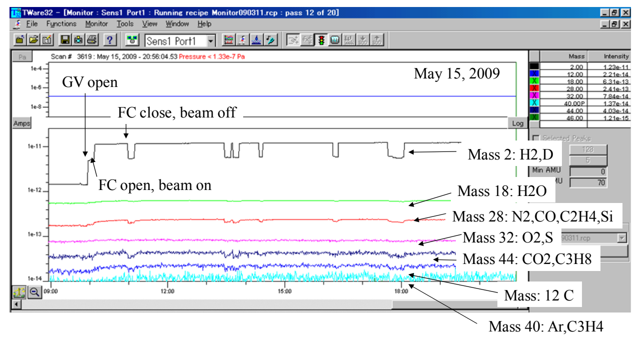

Figure 2: Measured data from the Q-mass analyzer.

In July we began a 10 day baking process to accelerate degassing. Since the RFQ structure itself was not designed for baking and some Viton O-rings are used, we had to limit the maximum temperature to 70 degrees. We installed a temperature controlled cooling water system, and sheath heaters as well as aluminium foils around the vacuum vessel as shown in Fig. 3. To prevent local stresses, we made only very slow temperature rises and falls (1 deg/hour) keeping the water and structural temperatures very close. Figure 4 shows the vacuum pressures and temperatures during baking. We raised the temperature during the daytime and held it constant at night. As the temperature rose, much outgassing occurred. The major gas component was water (18), but and others with masses of 12, 22, 2, 14, 28, etc were observed. The vacuum pressure improved after baking. For example, comparing before and after vacuum at 50 deg-C, the pressure dropped to about a quarter of where it had been (3.9e-7 Pa, and 1.0e-7 Pa).

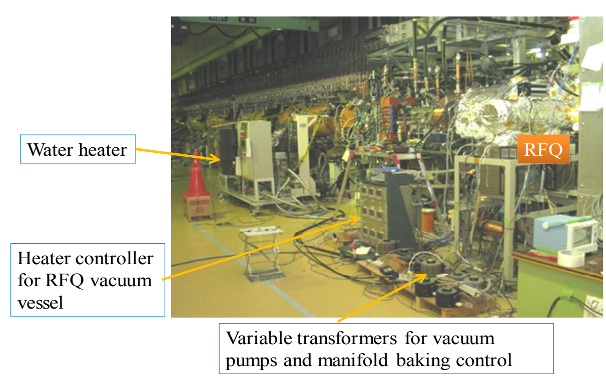

Figure 3: Baking of the RFQ.

On the upstream side, i.e. the ion source and LEBT, the size of the beam aperture at plasma electrode was reduced from 9 to 8mm, and the hydrogen gas flow rate was reduced by half.

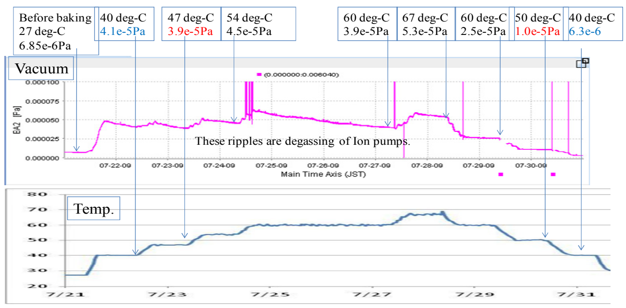

Figure 4: Vacuum pressure and temperature during the baking process.

OPERATIONAL EXPERIENCE AFTER THE VACUUM IMPROVEMENTS

Along with the vacuum improvement, since April 2009 the RFQ vane voltage has been decreased from 102% to 95 % of normal. Previous beam study results had shown that a higher vane voltage gives a better on/off ratio of intermediate chopping and less beam loss at the 3 GeV synchrotron. We confirmed that the worsened loss level would be acceptable for the lower beam power, and we chose it for more stable operation of the RFQ which is a higher priority.

To reduce unscheduled beam shutdown, which naturally users dislike, conditioning days for RFQ clean up are scheduled in the operational calendar. At first, we set cycles of 2 or 3 days of operation followed by one conditioning day.

We did conditioning in September after the summer shutdown. In November, based on the stable operation of the RFQ at 20 kW in October, we tried to increase the beam power for MLF user operation; increasing beam pulse length from 0.1 to 0.2 msec, and peak beam current from 5 to 15 mA, thus giving a 6 fold increase from 20 to 120 kW. We were able to deliver beam to MLF users without incident.

In December we demonstrated 300 kW operation for one hour to the MLF. The linac and the RFQ delivered the beam with a pulse width of 0.5 ms, which is the full design specification. The results verified the restoration of the RFQ as well as the 3 GeV synchrotron performance[3].

In January 2010, we delivered beams to MLF and began trying to extend continuous operation to 3 days and more. Gradually we were able to extend to 6 or 7 days. In February, MLF operation was cancelled due to target trouble, but we delivered beams for 7 and 6 days without incident to the Hadron (HD) and Neutrino (NU) facilities, respectively.

Working to extend the continuous operational days, we monitored trend in the number of trips. The day after conditioning, the number of trips was least and it seemed to be increasing with the number of operation days. But the number was decreasing as operational days accumulated. Figure 5 shows the number of trips per day due to the RFQ for the latest run in May. Most of the time, beam is delivered to the MLF (0.2ms, 25Hz) and NU (0.5ms, 0.3Hz). The blue dots show the success of automatic trip recovery, and red dots show failures where operator assisted recovery was necessary, these are more severe than the automatic recovery cases. We have had many trips on some days, but there seems to be a recovery even when in continuous beam operation. Thirteen consecutive days of operation without degradation have been demonstrated, which means that the performance of the RFQ has been almost restored to what it was.

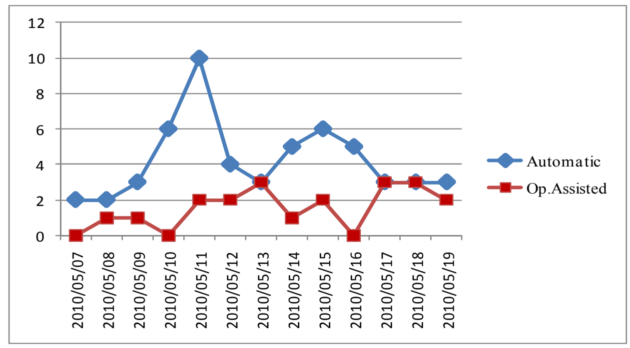

Figure 5: Number of trips per day in the latest run.

Figure 6 shows long term residual gas components during conditioning. The water component 18 is nearly constant, but hydrocarbon related components such as 2, 28, 44, 12 and 40 are almost half of what they were in September. Performance restoration of the RFQ is thought be due to the effect of de-gassing of these hydrocarbon components.

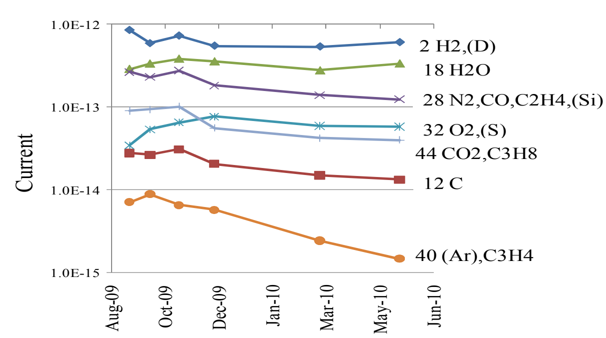

Figure 6: Long term residual gas components during conditioning. Note that the duty factors and voltage levels are not the same as the condition has been getting better.

REFERENCES

[1] T. Morishita, et al., "Fabrication of the New RFQ for the J-PARC Linac", MOPD044, in these proceedings.
[2] Y. Kondo, et al., "Thermal Characteristics of a New RFQ for J-PARC", MOPD043, in these proceedings.
[3] M. Kinsho, "Status and Progress of the J-PARC 3-GeV RCS", MOPEC069, in these proceedings.